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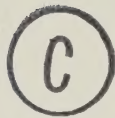
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INFORMATION, PROCESSING TIME AND PREFERRED
ADJECTIVE ORDER IN ENGLISH

by



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A THESIS

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ABSTRACT

The current research was designed to test a proposed model of the noun phrase decoding task. Subjects were required to identify which of four possible triangles, varying in size and color, were defined by a sequence of slides containing size and color information. On the basis of the model it was predicted that reaction times (RT's) to identify would be shortest when size came first, as in preferred adjective order in English noun phrases. The model also predicted redundant series (series in which the first slide's information was repeated on the second slide) would produce shorter RT's than nonredundant series. A simpler model predicted that RT's would be shortest when the interval between slides (ISI) was a minimum.

It was found that RT's were significantly shorter to redundant series but that RT's were only shorter to preferred order in redundant series. Varying ISI produced no significant differences in RT but its interaction with attribute order was significant such that RT's to preferred order were significantly shorter only when the ISI exceeded 100-msec. These results were interpreted as supporting the proposed model and not supporting the simpler model.

Two control experiments were conducted. The first compared RT's in identifying single attribute figures and sequentially presented bi-attribute figures. The latter corresponded to nonredundant series including both preferred and nonpreferred order. RT's to single attribute figures were significantly shorter and a comparison of means indicated that size attributes took less time to identify than color attributes.

This contradicts earlier findings. The second control experiment compared RT's in identifying bi-attribute figures presented sequentially and simultaneously. Sequential series included both order conditions and both redundancy conditions. Nonredundant series required significantly more time to process than redundant series and simultaneously presented figures. These results were generally interpreted as supporting the model. The failure to obtain differences in RT to attribute order was explained in terms of the order by ISI interaction from the first experiment: The control experiments employed an ISI too brief (50-msec.) to produce such differences.

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Introduction

There are several possible orders for multiple adjectives in a given noun phrase yet only one will be considered correct by native speakers of English and it will occur most frequently in spontaneous speech. For example, the large red chair is an acceptable description of a chair that is both red and large while the red large chair is not. The rules governing this phenomenon are not obvious, but they must be found either in the syntax and the semantic component of the noun phrase or in the psychological processes which generate and comprehend language. This thesis is concerned generally with the interaction of the cognitive component with syntactic and semantic aspects of adjectives differing in ordinal position. The relation of syntax to the differential processing time of ordinally different adjectives is investigated and a model of the decoding process, similar to the more general analysis by synthesis, is proposed and tested by manipulating redundancy.

Linguistic Theories

Syntactic Hypotheses. Syntax has generally been found inadequate in explaining the phenomenon. Annear (1964) proposed three order classes such that any two adjectives could be ordered by comparing their class membership. Adjectives belonging to classes preferred closer to the noun would appear closer to the noun in the phrase. However, as Martin (1969b) properly concluded, Annear's explanation is inadequate since the only evidence for the existence of order classes was the adjective

order phenomenon which they were to explain.

Another syntactic explanation was offered by Vendler (1963) who defined order classes by the type of transformation necessary to generate a noun phrase containing an adjective. Different transformations were proposed for adjectives preferred in different positions relative to the noun. For example, the red chair was derived from the chair is red by $N \text{ is } A \rightarrow AN$ while transforming the chair is large for a chair to the large chair required $N \text{ is } A \text{ for } N \rightarrow AN$. In the large red chair, the transformation introducing red was to have been applied prior to the transformation introducing large, thus accounting for the observed order. Martin (1969b) considered this explanation post hoc since no evidence for the ordering of transformations was offered other than the ordering of adjectives and Katz (1964) attacked the suggested differences in transformations by pointing out that only one kind of transformation was necessary to generate all adjective-noun phrases ($N \text{ is } A \rightarrow AN$).

Semantic Hypotheses. Several investigators have studied the relations between semantic dimensions and adjective order. Ziff (1960) noted that adjectives differ in the extent to which their denotations depend upon the noun they modify and called this dimension "definiteness of denotation". He found that adjectives which referred to the same property regardless of the noun's meaning and were thus definite in denotation were preferred closer to the noun than adjectives indefinite in denotation. This had been considered by Sweet (1898) who also noted that adjectives closer to the noun in meaning (i.e. those which denoted inherent or

essential properties of the noun) were preferred closer to the noun in noun phrases.

Martin (1969b) used the paired-comparison technique to obtain ratings on these two dimensions as well as imagery and absoluteness (absoluteness was defined by the number of comparisons between objects that would be necessary to decide upon a particular adjective such that absolute adjectives required the fewest comparisons). The obtained ratings were correlated with order judgements. All correlations were positive but analysis of partial correlations indicated that imagery and closeness to the noun in meaning correlated with order only because of their correlation with definiteness. Definiteness and absoluteness were taken to be indicators of context dependence in the adjective selection phase of noun phrase encoding. Definite, absolute or context independent adjectives were considered to be more accessible to selection and hence appeared closer to the noun.

Danks and Glucksberg (1971) suggested that Martin's absoluteness and definiteness dimensions could be combined under an intrinsicness dimension which would better predict adjective order. Intrinsicness could predict the order of the eleven adjective classes described by Brown (1965, p.282) whereas definiteness could predict only two. High intrinsic adjectives referred to properties central to the nature of the object such as place of origin in the Swiss watch. Superficial properties, such as color in the gold Swiss watch, were lower in intrinsicness. Low intrinsic adjectives referred to properties that were relative to some reference object or condition such as size in the large gold Swiss watch.

Adjectives that referred to properties most intrinsic to the noun were seen to be the poorest discriminators between noun objects and were preferred closest to the noun. Low intrinsic properties which depended on the noun in relation to other nouns (e.g. size) allowed better discriminations and were preferred farthest from the noun. This semantic rule operated in conjunction with a pragmatic communication rule which placed emphasized information nearest to the beginning of a sentence or phrase. Thus adjectives allowing the best discrimination between nouns appeared first in the noun phrase and, since adjectives precede the noun, farthest from the noun.

Psychological Theories

Encoding Theory. Martin (1969a, 1969b, 1970) proposed a theory of noun phrase encoding¹ which, in interaction with definiteness and absoluteness, accounted for adjective order. For a noun phrase to be generated, the noun's meaning would be scanned by a cyclical scanning process which would output the noun and the relevant adjectives. Adjective order in the resulting noun phrase was the inverse of the order of selection of adjectives; adjectives selected first appeared closest to the noun. Selection priority was determined by the definiteness of the adjective which indicated dependence of the adjectives on the noun's meaning such that adjectives depending the least would be selected first. Thus definite adjectives were selected first and consequently appeared closest to the noun in the noun phrase. The cyclical nature of the scanning process allowed Martin (1970) to account for the juncture

phenomenon in nonpreferred order. When adjectives are produced in nonpreferred order, a pause or juncture between the adjectives is obligatory (e.g. the red, large chair). Adjectives before the juncture were considered to modify the entire adjective-noun compound following the juncture while adjectives after the juncture modified only the noun. For Martin, the juncture represented a separation of two cycles of the scanning process. Adjectives independently modifying a noun would be selected and produced in a noun phrase in correct order by the first cycle of the scanning process while adjectives modifying the first cycle's noun phrase would be produced, again in correct order, by the second cycle.

The priority of selection rule was inferred from the results of two experiments. In the first (Lockhart and Martin, 1969) adjectives preferred closer to the noun were found to produce better recall of adjective-adjective-noun triplets when used as cues for recall than did adjectives preferred farther from the noun. This was interpreted as stronger association strength and consequently greater accessibility for adjectives preferred closer to the noun. However, these findings could be accounted for solely by intrinsicness. Adjectives preferred close to the noun are redundant with the noun's meaning and would be expected to elicit the noun better than a less related cue.

In the second experiment (Martin, 1969a) subjects were presented with figures varying in two attributes and were required to produce vocally the value of an attribute when cued with its generic name. Adjectives preferred farthest from the noun took longer to be produced than adjectives preferred close to the noun. This was taken to be

strong support for the differential accessibility of ordinally different adjectives in the encoding process, but the effects of encoding were confounded with visual decoding of the arrays. Martin's theory required his subjects to scan the meaning of the noun to select the relevant adjectives; his experiment required subjects to scan a visual array. The differential reaction times may have been a direct result of the number of comparisons between figures necessary to decide upon the appropriate adjective. To decide size, subjects would have had to compare the target figure with other figures until one different in size was found. The direction of the difference would have indicated which of the two size adjectives to select. On the other hand, color may have been decided by inspection of the target figure alone.

To support his encoding interpretation, Martin (1969a) conducted a decoding experiment and found no significant differences in the time required to decode ordinally different adjectives. He concluded that the differences obtained in the encoding studies represented real differences in the encoding process. However, the appropriateness of the study as a test of decoding is questionable. Subjects were directed to a particular figure on an array and presented with the verbal label of an attribute value. They indicated the correspondence between the figure and the cue by saying "true" or "false". No differences in reaction time to ordinally different adjective cues were obtained. A statistical error may have obscured any real differences. "True" and "false" responses which have generally been found to produce significantly different reaction times (e.g. Collins and Quillian, 1969) were not

differentiated in Martin's analysis of variance. This would have greatly increased the error term while adding only one degree of freedom and consequently may have obscured existing differences.

Also, the subjects may not have processed the stimulus information in the same manner as subjects in the encoding studies. In the encoding experiments, subjects could benefit only by waiting for the attribute cue before searching the array for its value while in the decoding study verbally encoding the figure prior to adjective cue presentation would make the task easier since the attribute cue, also verbally encoded, could be submitted directly to an identity comparison with the encoded visual figure. If the correct response to the cue was "true", the encoded cue should be identical with one of the elements of the encoded figure; if no identity was found a "false" response would be appropriate. Thus in the decoding study the dimension itself was not important to the task although Martin had argued that the dimensions are processed differently.

Consequently, it may be assumed that the obtained differences in reaction time in the cued production task were the result of visual decoding rather than verbal encoding. Postulating differential accessibility of adjectives on the basis of this evidence requires assuming that information stored in memory is represented in the same form in which it is input visually. Adjective accessibility in verbal encoding from memory would match accessibility in a visual array only if this were true. The unlikelihood of this assumption has been eloquently argued by Neisser (1967) in his discussion of the transformation of information passing from sensory to semantic states.

Decoding Theory. An alternative theory was proposed by Danks et. al. (Danks, 1971; Danks and Glucksberg, 1971; Danks and Schwenk, 1972). In their view of noun phrase generation adjectives were ordered for output on the basis of a pragmatic communication rule which required that emphasized or important information occurred first in the resulting noun phrase. Adjectives less intrinsic to the noun were more discriminative, hence more important, and were consequently placed first in the noun phrase, farthest from the noun. Evidence for the rule was obtained in a study (Danks and Schwenk, 1972) in which subjects more frequently chose inverted adjective order as the best description of a multiple attribute object presented with other similar objects if the attribute represented by the adjective occurring first in inverted order (normally preferred closest to the noun) allowed that object to be discriminated. Under other conditions, inverted order was chosen far less frequently. Another study (Danks, 1971) showed that the rule was important to decoding. When given spoken noun phrases as cues and required to identify the phrases' referent objects from groups of four, subjects' reaction times to identify were always shorter when the first adjective in the noun phrase allowed discrimination of the target object. Shorter reaction times to preferred order occurred consistently only when both attributes were necessary to identify the target object.

While demonstrating the communication rule, Danks and his colleagues did not attempt to define the psychological processes responsible for the rule. Their experiments suggest the decoding process. Inverted order may be used to describe an object if it "sounds best". Stress and

juncture, both articulatory variables altering the input sound pattern, were shown to effect ratings of grammaticality of inverted order noun phrases (Danks and Glucksberg, 1971) and the frequency of choice of inverted order as the best description of an object (Danks and Schwenk, 1972). These data, especially the latter study, may be taken as indicating that noun phrases are encoded and articulated so as to be most acceptable to the decoder. The importance of this consideration is suggested by Stolz' (1967) finding that left branching structures are especially difficult to decode. Since the structure of English multiple adjective noun phrases is left branching, they must be difficult to decode and it is possible that the nature of the decoding process is such that certain input orders are easier to process than others. If so, the optimal order should be definable in terms of semantic criteria (i.e. the communication rule). The major concern of this thesis is the proposition and testing of a model of such a decoding process.

The model must in some way deal with the difficulty of decoding a left-branching structure and with Martin's (1969a, 1969b) claims that for indefinite adjectives which occur first in the phrase the noun's meaning must be known for the complete meaning of the adjective to be specified. A possible model would be a push-down store system in which the input adjectives would be held in storage until the noun was decoded. Then the adjectives would be retrieved in the inverse of the order of input; last in, first out. This alleviates the problem of a left-branching structure by reflecting it to a right-branching structure. Since adjectives are decoded after the noun, Martin's problem of nomial

dependency is solved. In addition, this model accounts for the equivalence, if order is defined in terms of closeness to the noun, of preferred adjective order in left-branching English and right-branching Indonesian noted by Martin (1969a). An object described as the large red chair in English would be described as the chair red large in Indonesian. This model would posit that at the time of decoding, all adjective-noun phrases were right-branching, regardless of language. Thus whatever cognitive advantages maintained order preferences in one language would also maintain them in the other.

The unlikelihood of this model is suggested by the intuitive knowledge that adjectives can be processed, at least to some extent, without the noun. For example, the relational meaning of large in the large red chair can be discerned without knowing the range of size values large occupies for that noun. We know that the noun is bigger than some standard even if we do not know which standard. This prior processing can be demonstrated by a simple experiment. Ask subjects to choose one object out of four on the basis of an adjective cue. If the adjective cue is presented before the four-object array is shown to the subjects and they are still able to find the object designated by the cue, they must be able to process the relational meaning of the adjective without knowing the domain of the relation.

A Decoding Model. It is possible that preprocessed adjective information could be used to select the important aspects of the noun's meaning prior to decoding the noun, thereby simplifying the decoding task. The model tested in this thesis was based on that assumption.

The task of decoding a noun phrase may be viewed as a series of decisions constructing some representation of the particular configuration of meaning encoded in the phrase from the sequence of input information. As each adjective is input, decisions about its meaning and about the meaning of its phrase are made. This can be construed as requiring two kinds of decisions; decisions about the specific meaning of each unit and decisions about the meaning of the unit in the phrase (i.e. the meaning of the adjective dependent on the noun). The specific meaning of the adjective would be decided by terminal decisions since this information could be specified in the immediate decoding of the adjective, while the dependent component which requires the noun's meaning to be specified would be processed by a non-terminal decision. A nonterminal decision would be a decision not to terminate processing that meaning until further information is obtained, and could take the form of a query into the semantic space of the incoming noun for the dependent meaning of the adjective. An example will illustrate. In decoding the large chair, the relational meaning of large - i.e. "bigger than" - can be decided without processing chair. This is a terminal decision. The absolute size or the range in size referred to be large for chair can be decided only after chair has been decoded. The decision about this aspect of large's meaning made at the time of decoding large is a nonterminal decision. Its effect would be to produce a query into chair's semantic space for the meaning necessary to completely specify the adjective. The query for large would be "what standard size is this object bigger than". In effect, the querying amounts to defining a search strategy into the noun's meaning

since it defines priorities for retrieving certain aspects of the noun's meaning. Thus nonterminal decisions would facilitate noun phrase processing since they pre-select aspects of the noun's meaning important to the meaning of the phrase and consequently the task of decoding the noun is made less complex.

The advantage of preferred order lies in having adjectives requiring nonterminal decisions come first so that optimal search strategies may be set up as early as possible. This would be useful in reducing interference at the time of noun decoding. If adjectives requiring nonterminal decisions occurred next to the noun, their decoding and the establishment of search strategies would continue after the noun had been input, increasing the amount of information that must be handled, producing interference. Placing an adjective easier to decode - i.e. one requiring only terminal decisions - between such adjectives and the noun would reduce the amount of interference present when processing the noun. This would become increasingly important as the number of adjectives in the phrase increased since the amount of specific information would be greater, increasing the need to reduce the complexity.

Whether or not an adjective requires a nonterminal decision in its decoding can be decided on the basis of the rated definiteness and intrinsicness of the adjective. If subjects are asked to rate adjectives on the extent to which their meaning in a phrase depends on the modified noun (i.e. definiteness) then adjectives, rated as having a high degree of dependency can be considered to require nonterminal decisions. Similarly, requiring subjects to rate adjectives on the extent to which

they represent information that is not implicitly contained in the noun or redundant with the noun (i.e. intrinsicness) would also differentiate adjectives requiring nonterminal decisions. Nonredundant adjectives would require nonterminal decisions. This formulation relates the current model to the work of Danks and Martin, specifically their demonstrations of the correlation between the above dimensions and adjective order, but does not imply commitment to their conceptual definitions. Definiteness and intrinsicness as they relate to the current model are, in effect, operationally defined independent of the confused conceptual definitions given by Danks and Martin. The current model goes beyond their work in relating the dimensions to the way in which adjectival information may be processed; their work was primarily correlational.

However, the current model is not an unlikely interpretation of the role of definiteness and intrinsicness in their theories. Both Martin (1969b) and Danks and Glucksberg (1971) noted that adjectives which were rated as requiring the most decisions or comparisons between objects to be chosen were preferred farthest from the noun. This occurred because they carried more important or discriminative information about the meaning of the noun phrase. Martin (1969a, 1969b) has noted that this information depends more strongly on the noun's meaning since adjectives preferred farthest from the noun were indefinite in comparison with adjectives preferred closer to the noun. Because nonterminal decisions resolve the dependency of the adjective's meaning on the noun, adjectives preferred farthest from the noun must require nonterminal decisions in their decoding. Adjectives preferred closer to the noun

tend to refer to properties more intrinsic to the noun itself and so their meaning is redundant in the noun phrase (Danks and Glucksberg, 1971; Danks and Schwenk, 1972). The information handled by nonterminal decisions refers to the meaning of the noun phrase itself. It consists of the interaction between the noun's meaning and the adjective's meaning. Intrinsic adjectives are highly redundant with the noun's meaning and would not contribute much to the interactive or dependent meaning in the phrase. Such adjectives would not require nonterminal decisions and are placed closest to the noun when used with less intrinsic adjectives.

Thus preferred order facilitates decoding because information presented in this order allows the decoder to set up search strategies into the noun's meaning in preparation for decoding the noun, easing the task of selecting information from the noun's meaning appropriate to the noun phrase.

It is possible that this model could be an instance of a more general model of language decoding. Contextual dependencies are characteristic of language and a decoding theory must account for their processing. In the current model the dependency is represented by a nonterminal decision, formed at the initiation of the dependency, which sets a priority for obtaining information that will allow resolution of its dependency. Thus decoding a string "in context" means querying each input unit for information that would resolve the dependency. An instance of the importance of contextual dependency in facilitating decoding is Stolz' (1967) investigation of the difficulty of decoding embedded left-branching structures. When the noun-verb-noun pairs of an embedded clause

semantically depended on each other decoding was easier than when all noun-verb-noun combinations were semantically possible. For example, the stone that the boy that the club members initiated threw hit the window is relatively easy to paraphrase while the chef that the waiter that the busboy appreciated teased admired good musicians is not.

In the first sentence it is obvious that the boy threw the stone and did not initiate it, whereas in the second sentence it is not easy to decide whether the waiter teased, admired, or appreciated either the chef or the busboy. Thus when resolution of contextual dependencies is possible in a language phenomenon other than adjective order decoding is also facilitated.

This model is very similar to analysis by synthesis, a general model of recoding or pattern recognition that has been applicable in a great variety of situations. It has been proposed as a model of visual and auditory attention (Neisser, 1967), speech perception and production (Halle and Stevens, 1964; Stevens and Halle, 1964; Liberman, Cooper, Shankweiler and Studdert-Kennedy, 1967) and the higher cognitive functions of semantic processing and thinking (Neisser, 1967).

Basically, in analysis by synthesis, the input data is compared with a restricted set of probable matches generated at a higher level of organization and the input is characterized at the higher level by the best fitting match. The restriction of the comparison set from the set of all possible matches is accomplished by the constraining effects of contextual expectancies and preprocessing the input data. Thus in synthesizing the meaning of a noun phrase, acceptable meanings would be

restricted by the contextual effects of queries into the noun's semantic space and the meaning of the noun input itself. In this way the set of all possible meanings is reduced to a small set of highly probable meanings. Hence the current model of the decoding process may be considered an instance of analysis by synthesis, further suggesting its generality.

Testing the Model. In the experimental test of the model, it was considered that the decoding task amounted to constructing a representation of the particular interactive combination of separate pieces of information presented sequentially and that the current model accomplished this by using early information to partially construct aspects of the interaction so that decoding the last item and deciding upon the interactive meaning was simplified. Obviously the test must involve manipulating the relation between early events and the interactive meaning to assess its effects on decoding difficulty. Repeating early information while presenting later information should be facilitative since the redundant information would not interfere with the partial construction. Not repeating such information or presenting inconsistent information should impair decoding by interfering with the partial construction. If the pieces of information were representable by adjectives preferred close to and far away from the noun, then varying the presentation order should define the relation between such consistency and adjective order - i.e. consistency should make less of a difference with attributes preferred closer to the noun since they tend not to generate nonterminal decisions.

The present experiment used pictorial stimuli to represent the

information and presented them sequentially. Subjects were required to combine the information in two sequential stimulus slides in order to select the appropriate response. Pictorial stimuli were used because they allowed manipulation of the experimental variables and because the model and the adjective order phenomenon in general referred to semantic processing of sequential information and should be independent of the perceptual mode that does the initial processing. In the experiment consistency was manipulated by repeating the first slide's information on the second slide. This produced two kinds of series - redundant series in which the first slide's was repeated, allowing an aspect of the series' meaning independent of the second attribute to be processed consistently with the representation constructed from early (first slide) information, and nonredundant series in which the first slide's information was not repeated so its processing in the second slide would not be consistent with the processing from the first slide. This could not have been done with words, whether presented visually or auditorily. Adjective order was manipulated by having the first slide represent size and the second represent color in the preferred condition and vice versa in the nonpreferred order.

The experimental design allowed the testing of another simpler model, suggested by Martin's (1969a) differential processing time data. Earlier it was shown that those data could be reasonably interpreted as differences in the decoding times of ordinally different adjectives. Since the task is viewed as the combination of pieces of information presented separately in time, it is possible that order effects the interval between the

availability of decoded adjective and noun meanings to the process combining them into the phrase's meaning and that varying this interval could effect ease of decoding. In preferred order the adjective which takes the least time to decode is placed next to the noun in a noun phrase, minimizing the interval between the first adjective and the noun. In nonpreferred order, the adjective which takes the most time to decode is placed next to the noun, maximizing the interval. It is possible that minimizing the interval facilitates combining the information in the adjectives and noun. This hypothesis has some general validity in view of the experimental literature. The importance of minimal interstimulus intervals has been made apparent in the areas of punishment (e.g. Kamin, 1959) and classical conditioning (see Kling and Riggs, 1971, p.557-559). This hypothesis was easily tested in the present experiment by varying the interval between information slides.

Statement of Problem

The proposed analysis by synthesis and minimum interval models contained implicit predictions about the ease of processing sequentially input information. These predictions constituted the following experimental questions which were tested in the current research:

- (1) When separate pieces of information must be combined, does preferred order facilitate this process? Both models predict facilitation; the minimum-interval model unconditionally predicts facilitation while the other would submit that conditions may exist under which preferred order would not facilitate processing (i.e. the

experimental conditions of Danks et. al.).

(2) When separate pieces of information must be combined, will a consistent relation between early information and the subsequent combination facilitate the processing of the combination? The analysis by synthesis model predicts facilitation, though facilitation may depend on the type of information which comes first (i.e. facilitation may depend on the preferred ordinal position of the early information).

(3) When separate pieces of information must be combined, does the interval between the availability of the pieces affect the combination process? The minimum-interval model predicts that decreasing this interval facilitates processing.

General Method

Design and Stimuli. The current research involved three separate experiments. The task in each experiment required Ss to identify a total figure (bi-attribute triangle) from information presented pictorially in a series of three slides. Each trial consisted of three slides referring to a particular bi-attributed figure. Subjects were to use the information in the second and third slides to decide which figure from a set of four possible figures had been defined by the series. The first slide in each series only signalled the initiation of a trial and contained the standard values of both attributes, providing no information about the series' referent figure. Subjects responded by pressing the button corresponding to the figure defined by the series and the latency of each response was recorded as the dependent measure of decoding difficulty. A representation of the events occurring on a typical trial is displayed in Figure 1.

Correspondence between the buttons and the triangles was varied between groups in all experiments since pilot work reported in Appendix A indicated that this accounted for a significant portion of the variance. The buttons were presented in a square array and under one condition the rows corresponded to values of the size dimension and the columns corresponded to values of the color dimension while in the other condition, rows corresponded to colors and columns corresponded to sizes. Three sizes were used: large, small and standard. Standard size was not relevant to the size dimension but was used in the first slide in each series and whenever color information was presented without size information. Three colors were used: red, green and white. Again, white was not

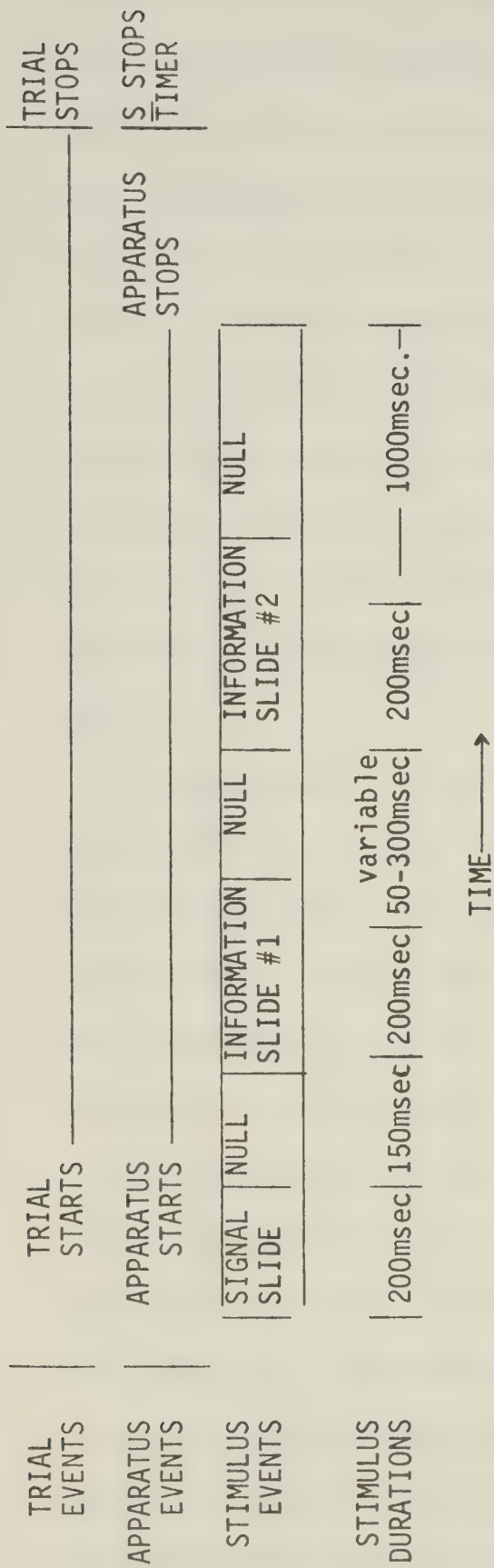


FIGURE 1
A TYPICAL TRIAL

relevant to the color dimension but was used in the first slide and whenever size information was presented without color information. The stimuli were 16mm. negatives of black equilateral triangles, varying in size, photographed on a white background. Consequently they appeared on the display unit screen as white triangles on a black background. The altitudes of the triangles as displayed on the screen were 3-in., $1\frac{1}{2}$ -in., and $3/4$ -in. for large, standard and small sizes, respectively. Red and green Venus Vis a Vis flow pens developed for use with transparencies were used to color the slides. White slides were left uncolored. Using all combinations of size and color produced nine negatives which were mounted on a plastic slide inserted in the display unit.

The presentation order for size and color in the second and third slides took two values: size-color or preferred order and color-size, nonpreferred order. Two kinds of series were used: redundant series representing the consistent condition and nonredundant series representing the inconsistent condition. In a nonredundant series the second and third slides each contained information about only one attribute while in a redundant series the third slide contained information about both attributes, repeating the information in the second slide as well as specifying the value of the remaining attribute.

Apparatus. The slides were displayed on the 3-X5-in. screen of an IEE Model 80-0000-1495 visual display unit. The sequence of slides in a series was specified by the six event program of a tape which, when passed through a tape reader, determined the visual display. In order

to control the intervals between the slides as well as the on-durations of the slides, null events were included on the tape which produced a blank screen for the second, fourth and sixth intervals. The triangles initiating the trial and defining the series' referrent figure occurred in the first, third and fifth intervals. The durations were controlled by a series of six Model 100-C Hunter Timers such that the onset of each timer advanced the tape one event and the offset of each timer but the last initiated the next timer in the series. Exposure durations for all events containing information were 200-msec., while the durations for the first and last null events were 150- and 1000-msec., respectively. The second null event, occurring between the presentation of the second and third information events varied between 50- and 300-msec., depending on the experiment and the conditions within experiments. These durations were selected on the basis of pilot work reported in Appendix A. Onset of the fifth timer, initiating the last information event, also started a Hunter Model 120A KlockCounter which was stopped by S's button pressing response. Subjects were seated approximately three feet from the display screen behind a partition separating them from the remainder of the apparatus. Four single-pole double-throw buttons mounted in a 1 3/4-in. square array were given to Ss to hold on their laps. Pressing the buttons stopped the KlockCounter and turned on one of four 24-vdc. lamps, each of which corresponded to a particular button. The lamps were mounted beside the KlockCounter, allowing E immediate knowledge of the correctness of each response as well as its latency.

Procedure. Upon arrival at the laboratory, Ss were met by E,

accompanied to the experimental room and seated in front of the display unit. They were then asked to hold the box containing the button array on their laps and were told the correspondence between the buttons and the triangles. The button order condition each S ran under was determined randomly, prior to his entering the laboratory. Subjects were then told that their task was to identify triangles as quickly as possible by pressing the appropriate button when they appeared on the display unit screen. Subjects were given 60 pretraining trials in which they identified triangles from slides containing both attributes simultaneously. The four different types of triangles occurred with equal frequency and in semi-random² order. Each trial entailed six tape events but the first four and the sixth were null so that S viewed only one slide per trial.

Upon completing pretraining, Ss were told that in the next part of the experiment they were to identify triangles in the same manner but now size and color information would be presented on separate slides. The specific nature of these instructions depended on the experiment as did the task. In all experiments, Ss were told the correct response and the content of the slides in any trial in which they made an error.

Experiment I

Method

This experiment was the main experiment of the thesis, testing both the analysis by synthesis and the minimal-interval models. This involved including redundant and nonredundant series to test the

consistency hypothesis and including series in preferred and nonpreferred order, as defined earlier, to test the effects of order. To determine interval effects, the duration of the second null event, occurring between the information slides, was varied. The intervals used were 50-, 100-, 200- and 300-msec. These three variables were varied independently within groups while button-to-figure correspondence was varied between groups.

Instructions and pretraining were as described earlier in the general section. For the main part of the experiment, Ss were told that they now had to identify the same triangles from information presented sequentially. They were told that the first slide on each trial would be a signal that the trial was beginning and that the second and third slides contained the information necessary to decide the figure. Subjects were also told that the experiment used two types of series but that the task was the same for both series. Both series types were defined verbally by example. Two orders, two series types and four intervals produced 16 types of trials which occurred in semi-random order in blocks of 16 trials such that each type of trial occurred only once in each block. The experiment consisted of five blocks or 80 trials in which latencies were recorded.

Subjects were 20 introductory psychology students who participated in the experiment to fulfill course requirements, receiving only E's gratitude for their services. Only native speakers of English were used in the experiment.

Results

The data were obtained by computing the median reaction time (RT) in each treatment condition for each S over the last three blocks. Data from the first two blocks were not included since it was concluded from the frequency with which errors occurred that Ss were adapting to the task. The mean RT's across Ss for each main effect and significant interaction are displayed in Table 1. For the analysis of variance, the obtained data were reciprocally transformed to correct for heterogeneity of variance often found with latency data (Kirk, 1968) and analysed in a split-plot design (SP 2.224; Kirk, 1968), the results of which appear in Appendix B.

The between groups button order effect was not significant but it interacted significantly with attribute order ($F(1,18) = 4.54, p < .05$). This interaction appears in Figure 2. When the rows of the button array corresponded to colors, RT's to nonpreferred order were significantly shorter ($F(1,18) = 6.78, p < .05$) whereas preferred order RTs' were significantly shorter when the rows corresponded to sizes ($F(1,18) = 11.42, p < .01$). If the button array was cognitively organized on the basis of rows, these results suggest the operation of some response organization strategy in which responding was facilitated if the first slide in a series corresponded to a value of the attribute on which the rows were organized. Thus when rows corresponded to size, RT's were shortest when the first information in the series was size information. All remaining interactions with button order were insignificant.

TABLE 1

MEAN RT'S FOR MAIN EFFECTS AND SIGNIFICANT
INTERACTIONS IN EXPERIMENT I (IN MSEC.)

		ATTRIBUTE ORDER		
		Preferred	Nonpreferred	
Button Order	Rows Sizes	1092	1181	1137
	Rows Colors	919	898	909
		1006	1040	

		ATTRIBUTE ORDER		
		Preferred	Nonpreferred	
Interstimulus Interval	50 msec.	1032	1066	1049
	100 msec.	1049	1000	1024
	200 msec.	976	1052	1014
	300 msec.	967	1041	1004
		1006	1040	

		ATTRIBUTE ORDER		
		Preferred	Nonpreferred	
Redundancy	Redundant	943	1060	1001
	Nonredundant	1069	1019	1044
		1006	1040	

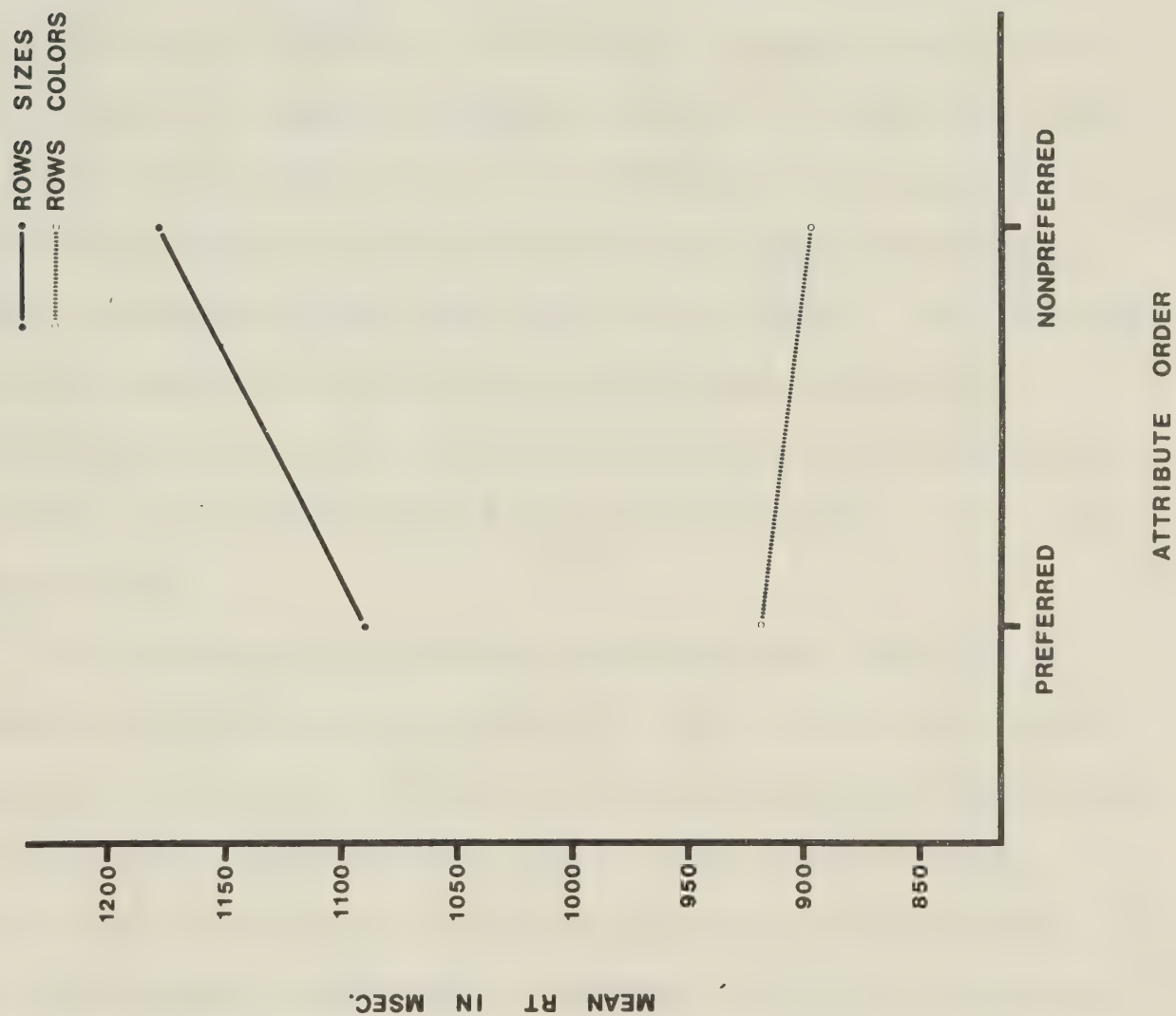


Figure 2. The Attribute Order by Button Order Interaction.

The main effect for attribute order was insignificant as was the interval main effect but they interacted significantly ($F(3,54) = 5.40, p < .01$). This interaction is displayed in Figure 3. Analysis of simple main effects (an F test for differences between levels of one factor at each level of another) indicated that varying intervals effected RT's significantly only when the information was presented in preferred order ($F(3,54) = 12.76, p < .01$). Inspection of Figure 3 shows that this difference indicates a drop in RT to preferred order as the interval increased from 100- to 200-msec. This suggests that facilitation occurred with preferred order only when the interval between information input exceeds some critical limit. This interpretation was supported by the finding that RT's were significantly shorter to preferred order than to nonpreferred order at the 200- and 300-msec. intervals ($F(1,54) = 4.47, p < .05$ and $F(1,54) = 3.67, p < .10$, respectively).

The redundancy main effect was significant such that RT's to redundant series were shorter ($F(1,18) = 9.05, p < .01$), confirming the consistency hypothesis. Redundancy also interacted significantly with attribute order, and this interaction is displayed in Figure 4. Simple main effect analysis indicated that RT's to preferred order were significantly shorter than to nonpreferred order in a redundant series ($F(1,18) = 14.14, p < .01$) but were significantly longer if the series was nonredundant ($F(1,18) = 7.26, p < .05$). Redundancy produced significant differences only when the information was presented in preferred order ($F(1,18) = 70.23, p < .01$). Since the redundancy factor

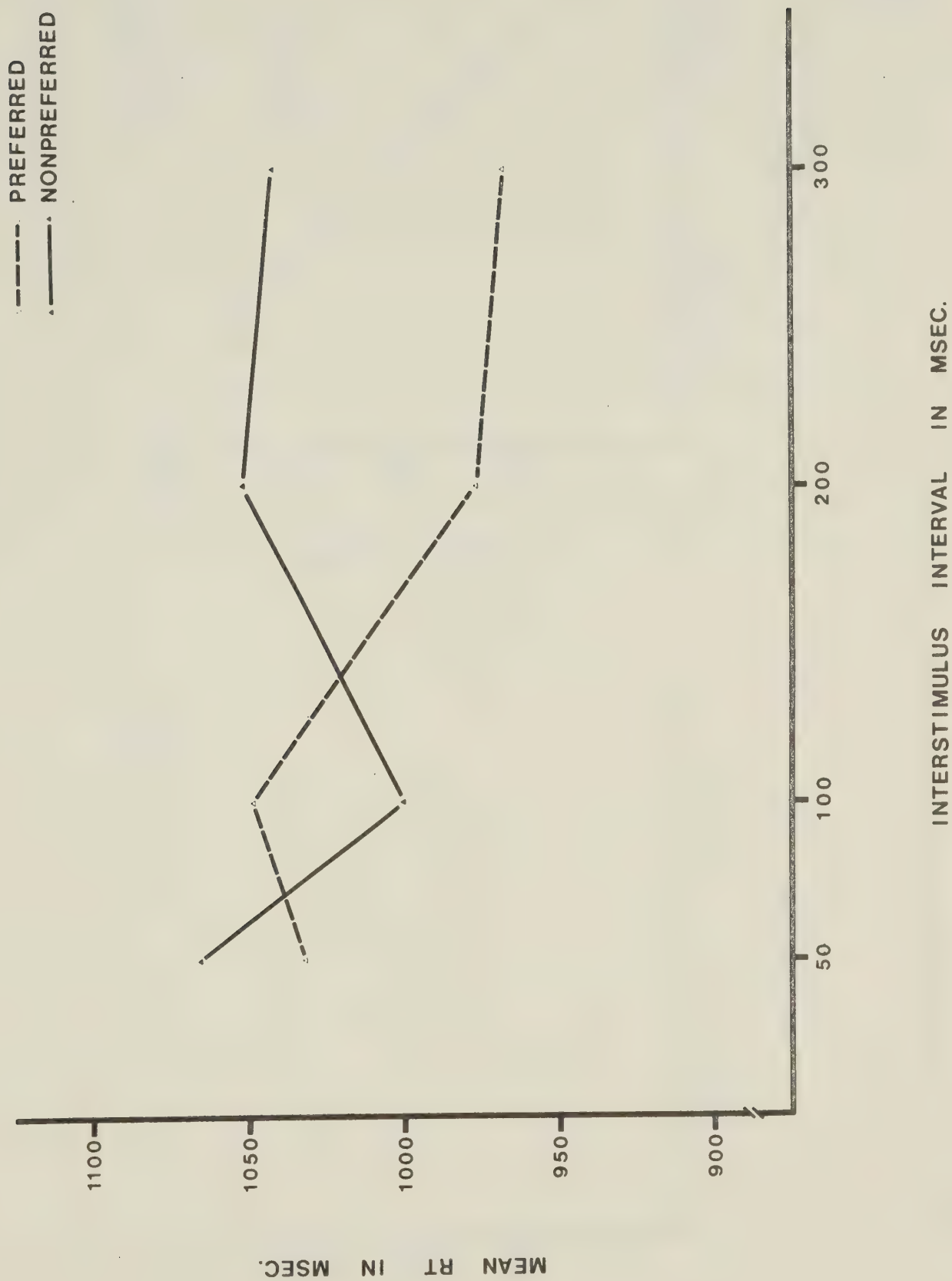


Figure 3. The Attribute Order by Interval Interaction.

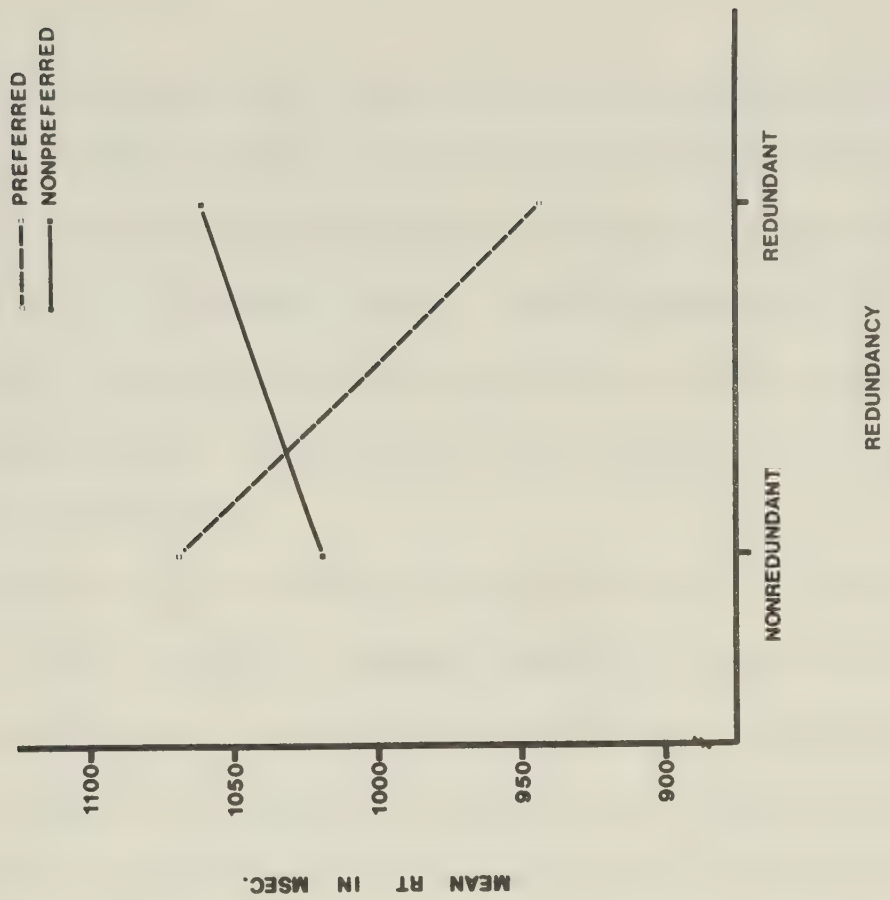
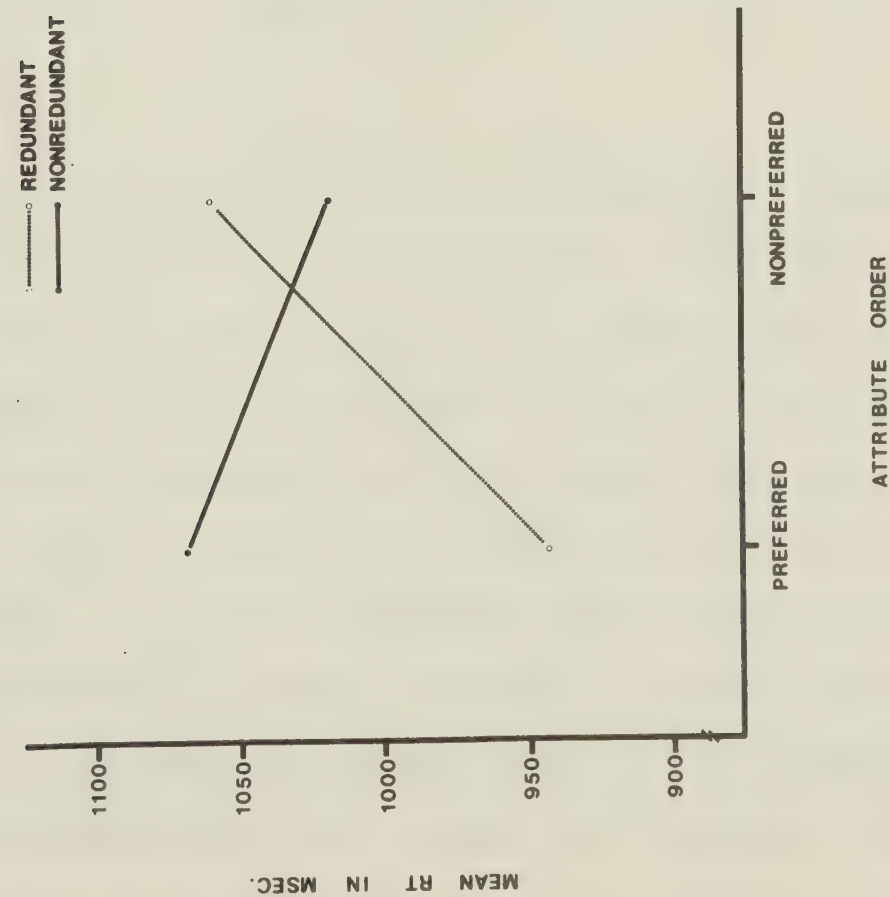


Figure 4. The Attribute Order by Redundancy Interaction.

represented consistency, this result was taken to indicate that size, which came first in preferred order, allowed the construction of a representation of the referent figure which facilitated processing when conditions permitted - i.e. in redundant series - and that color did not allow this since no facilitation was observed in redundant series. The interaction of redundancy with the interval factor was insignificant as were all higher order interactions.

The results of this experiment generally tended to confirm the hypotheses of the analysis by synthesis model but suggested that the interval hypothesis was too simplistic to account for interval effects obtained. However, in keeping the design of this experiment relatively simple, several important controls were omitted. Two further experiments were conducted to obtain proper control data.

Experiment II

Method

It was possible that RT's obtained in Experiment I represented only the time required to process the last attribute in the series. If this were so, it was also possible that RT's to preferred order would be spuriously shorter than RT's to nonpreferred order, because color, the last attribute presented in preferred order, took significantly less time to decode than size which occurred last in nonpreferred order (Martin, 1969a). The second experiment measured button pressing latencies in the identification of single attributes as a control for this possibility. Its purpose was to replicate Martin's (1969a) finding with the present apparatus and to compare the direction of any obtained

size-color differences with bi-attribute series ending in either size or color. The bi-attribute RT's were expected to be longer if anything other than the last attribute needed to be processed and a size-color main effect defined on the basis of the last information presented prior to the response in both single-attribute and bi-attribute conditions was to indicate the relation between single and multiple attribute processing. The bi-attribute condition was also a replication of the nonredundant condition of Experiment I, including both preferred and nonpreferred orders.

Single-attribute and bi-attribute conditions were run separately but used the same Ss, allowing statistical control of individual differences in RT. In the bi-attribute conditions, pretraining and instructions were the same as in Experiment I. Nonredundant series including both orders were presented for 12 trials following pretraining and latencies were recorded. Only data from the last six trials were analysed statistically. The type of triangle was ordered semi-randomly over the 12 test trials and each attribute order occurred three times in each block of six trials. Button orders, which were shown in Experiment I to produce significantly different latencies, depending on attribute order, were varied between groups in this condition. The order of assigning button order conditions to Ss was semi-random and was determined as Ss reported to the laboratory.

The on-durations for information events were 200-msec., as in Experiment I. The null event durations were 150- and 1000-msec. for the first and third (which followed the first and last information

slides) and 50-msec. for the second (which occurred between information slides). This latter interval was chosen following visual inspection of the attribute order by interval interaction in Experiment I on the presumption that it would avoid biasing the results in favor of preferred order.

In the single-attribute condition, button-to-figure correspondence was defined with size on the top row (large on the left; small on the right) and color on the bottom (red on the left and green on the right). Since both size and color were organized horizontally it was not considered necessary to vary button order, presuming that the organizational variables, whatever they may be, would equally facilitate or impair responses to both dimensions.

In this condition pretraining and test trials were run on the same tape, requiring only one instruction set to be given to Ss. The tape consisted of 72 six-event trials in which all events were null but the fifth. It contained information defining one value of one attribute. The task required Ss to identify the value of the attribute presented by pushing the appropriate button as quickly as possible. The first 60 trials were considered pretraining and differed only in that no latencies obtained from them were recorded. This resulted in a shorter intertrial interval than in the test trials where latencies were recorded. As in the bi-attribute condition, only the last six were analysed statistically. Size and color appeared equally often, though in semi-random order throughout the first 60 trials and within blocks of six in the last 12. The two different values of each dimension appeared

equally often within dimensions.

The reason for using 72 trials in this condition was to equate the number of trials in each condition.

The order in which the two conditions were presented was counter-balanced by assigning an equal number of S's to them randomly as the Ss reported to the experimental room. This assignment was independent of button order assignment since each task order occurred with equal frequency in both button order conditions.

Subjects were 20 introductory psychology students who participated in the experiment to fulfill course requirements. Again, all Ss were native speakers of English.

Results

The data were obtained by computing the median RT for each S over the last three trials in each treatment condition. These scores were reciprocally transformed to correct for possible heterogeneity of variance. Data from the bi-attribute condition were subjected to a split-plot analysis of variance (SP 2.2; Kirk, 1968) to assess the effects of the button order variable, varied between groups. No significant main effect was obtained from button order or its interaction with attribute order, so it was decided to pool the data with the single attribute condition. The summary table for the split-plot analysis appears in Appendix C.

Before transforming the data in the pooled analysis, mean RT's representing the main effects and the interaction were obtained. These

are displayed in Table 2. The reciprocally transformed data were analysed in a randomized block factorial analysis of variance (RBF 22; Kirk, 1968) which appears in summary form in the appendix. As expected, Ss' RT's were significantly different across conditions ($F(19,57) = 3.70, p < .01$). Bi-attribute RT's were significantly longer than single-attribute RT's ($F(1,57) = 37.14, p < .01$), adding credence to the hypothesis that something besides the last attribute was being processed in the nonredundant condition of Experiment I. No significant differences were found between size and color processing times, averaged across attribute conditions ($F(1,57) = 3.87, \text{NS}$) and the interaction between dimensions and number of attributes was also insignificant ($F(1,57) = 1.51, \text{NS}$). However, comparisons of all means by Duncan's new multiple range statistic (Kirk, 1968) revealed significantly shorter RT's to size than to color in the single attribute condition ($p < .05$) although no significant differences were obtained between size and color in the bi-attribute condition. The results of this analysis also appear in the appendix. This result is a direct contradiction of Martin's (1969a) finding for attribute identification with unrestricted exposure time.

The differential processing times for attributes observed in this experiment could be used to predict the order differences obtained with nonredundant series in Experiment I - RT's to nonpreferred order in which size was presented last were shorter than RT's to preferred order in which color was presented last. However, these RT's were among the largest in the experiment and so could not have depended on the processing

TABLE 2
MEAN RT'S IN EXPERIMENT II (IN MSEC.)

Number of Attributes		LAST ATTRIBUTE PRESENTED		
		Size	Color	
		783	871	827
	Single Attribute			
	Bi-Attribute	1051	1062	1052
		917	967	

time of the single attribute alone. This could also be concluded from the present experiment in which bi-attribute RT's were considerably longer than single attribute RT's.

Experiment III

Method

It was possible that Ss in a redundant condition would attend only to the last slide in the series since it contained all the information necessary for responding correctly so the third experiment was designed to compare figure identification latencies in a redundant series with latencies to single slides containing both size and color information. Any differences could be interpreted as the effect of the first information slide in the redundant series. Nonredundant series were also included so that Ss would find it necessary to process slides other than the last in at least some of the trials. Had they not been included, Ss could have responded on the basis of the last slide on each trial, thus weakening the effect of the first information slide. Again, button order was varied between groups.

Pretraining and pretraining instructions were the same as in Experiment I. Since Ss in Experiment I appeared to be confused by the different types of trials, four examples each of nonredundant, redundant and single slide trials were given to Ss prior to the test trials. For the test trials, Ss were instructed that the three kinds of trials would be given to them in "random" order and that they were to identify the

triangles referred to in each trial by pushing the appropriate button as quickly as possible.

The test trials were programmed on a six event tape with 200-msec. on durations for information slides and 150-, 50- and 1000-msec. durations for the first, second and third null events, respectively. The 50-msec. duration was chosen for the second null event on the basis of preliminary analysis of Experiment I data which indicated that this interval would not be likely to bias the results in favor of preferred order.

Redundant and nonredundant series were as defined for Experiment I. In single slide trials the information slide occurred in the last information event, preceeded by two standard triangles which did not in any way define the trial's figure. Both preferred and nonpreferred orders were included in each redundancy condition so that the experiment would be a partial replication of the order and redundancy effects in Experiment I. Thus there were five treatment conditions: redundant preferred order; redundant nonpreferred order; nonredundant preferred order; nonredundant nonpreferred order, and the single slide condition. An equal number of observations were made under each treatment condition.

The five treatment conditions corresponded to trial types and each occurred three times in a block of 15 trials. Including two blocks of 15 trials produced 30 test trials. Button order was again assigned semi-randomly with equal frequency to Ss as they reported for the experiment.

Subjects were 20 introductory psychology students who participated

in the experiment to fulfill course requirements. All Ss were native speakers of English.

Results

The medians of the three RT's to each trial type in the last block were computed for each S. The mean RT's across Ss in each treatment condition are presented in Table 3. These represent the cells of the split plot analysis of variance (SP 2.5; Kirk, 1968) which was performed on the reciprocal transformation of the data. The transformation was employed to correct any heterogeneity of variance. The summary of this analysis appears in Appendix D. As in Experiment II, button orders were not significantly different ($F(1,18) = 0.10$, NS) nor were their interaction with trial types ($F(4,72) = 1.68$, NS). RT's to trial types were significantly different ($F(4,72) = 8.78$, $p < .01$) so planned orthogonal comparisons were carried out to see if the differences predicted in this experiment and those predicted on the basis of Experiment I were obtained. Single trial RT's were not different from redundant series RT's, averaged over attribute order ($t(38) = 0.06$, NS). RT's to preferred and nonpreferred orders were not significantly different in both redundant and nonredundant series ($t(38) = 0.14$, NS and $t(38) = 0.05$, NS, respectively). Thus the significant F-ratio found in the analysis of variance can be interpreted as indicating only that nonredundant series required longer RT's than redundant series.

This experiment offered no support for the contention that the first

TABLE 3

MEAN RT'S IN EXPERIMENT III (IN MSEC.)

TRIAL TYPES	Single Slide	1022
	Redundant Preferred Order	1028
	Redundant Nonpreferred Order	1052
	Nonredundant Preferred Order	1308
	Nonredundant Nonpreferred Order	1303

information slide is important in figure identification in redundant series. As a replication of Experiment I, only the redundancy main effect was successful. The interaction which was crucial to the experimental hypotheses was not replicated. However, these results are better understood in the context of data from other experiments and will be interpreted in the general discussion which follows immediately.

Discussion

The results of the three experiments may be summarized as follows:

- (1) Redundant series were significantly easier to process than nonredundant series in both Experiments I and III. The redundancy effect was shown to occur only when the information was presented in preferred order in Experiment I but this effect was not replicated in Experiment III where redundant series were easier, independent of attribute order.
- (2) Interstimulus interval and attribute order produced no significant effects independently but interacted significantly such that interval effects occurred within preferred order but not within nonpreferred order.
- (3) Button order produced no significant differences in any experiment but interacted significantly with attribute order in Experiment I. This interaction was not replicated in Experiments II and III.
- (4) Size attributes were decoded significantly faster than color attributes. This is a direct contradiction of Martin's (1969a) results.
- (5) Redundant series RT's were not significantly different from RT's to single presentations of bi-attribute information.

The primary result to be explained is the interaction of redundancy with attribute order in Experiment I since it has the most relevance to the hypotheses of this thesis. The failure to replicate this interaction

in Experiments II and III may be understood if it is remembered that a 50-msec. ISI was used in those experiments. Analysis of the attribute order by interval interaction in Experiment I showed that the 50-msec. ISI produced no significant differences in order, hence it is not surprising to find no order differences in Experiments II and III. Thus selecting this ISI, having concluded that it would be unlikely to bias the results in favor of preferred order on the basis of visual inspection of the order by interval interaction, was unfortunate since it biased order effects towards nonsignificance.

To understand the order by redundancy interaction it is necessary to interpret the finding in Experiment III that single bi-attribute slides and redundant series were equally difficult to recognize. A possible interpretation is that only the last slide in redundant series was processed, but this is unlikely since redundant series were responded to very differently depending on the order in which the information was presented in Experiment I. This latter result would indicate that processing of the first information slide occurred since the series differed only on their first slides. Finding that single bi-attribute slides required the same amount of processing time as redundant series may be taken to indicate that both attributes of the last slide must be processed. This would explain the increased difficulty found in dealing with nonredundant series in Experiment III. The neutral value of the last slide may have been confused with the non-neutral value defined in the first slide and resolving the confusion may have required more processing time.

If it is concluded that the single attribute in the first information slide and both attributes in the second information slide were processed, it is appropriate to ask what effect the processing of the first slide had on the processing of the second. Analysis of the order by redundancy interaction indicated that this depended strongly on which attribute was represented in the first slide. If the first slide was size, a redundant series facilitated performance while a nonredundant series impaired performance. However, if the first slide was color, redundancy in the second slide had no effect. This may be understood in terms of the analysis by synthesis model which suggested that the function of adjectives preferred farthest from the noun was to generate a context which would facilitate subsequent processing. Thus when size came first in a series, as it does in a noun phrase, its decoding would generate a context in which the second slide would be decoded. The context would consist of a representation of the size value of the second slide, possibly deciding the priority of semantic tests to be employed on the input such that the size value in the first slide would be the first size tested in the second slide. If the series was nonredundant, the first test would produce negative results and other tests would have to be carried out to determine the size of the second slide. Once it had been determined, it would be necessary to decide which size value was appropriate to the series so that the correct response would be made, and this would require additional processing time.

Since the analysis by synthesis model suggested that color adjectives

would not generate a context no differences would be expected between redundant and nonredundant series with nonpreferred order, and this was the result obtained in Experiment I. This would be possible if the color tests were independent.

The facilitative effect of redundant series on preferred order was indicated by significantly shorter RT's to preferred order than to non-preferred order in redundant series while the impairing effect of non-redundancy on preferred order shown by the significantly longer RT's to preferred order in nonredundant series.

The attribute order by interval interaction is also explainable by this interpretation. No interval differences were obtained in the non-preferred order condition while significant differences to intervals were obtained with preferred order. Inspection of Figure 3 showed that increasing the ISI from 100- to 200-msec. resulted in a large drop in RT to preferred order and this drop continued, though only slightly, as the ISI increased from 200- to 300-msec. Order differences at these intervals were significant though the difference at the latter interval was only slightly significant ($F(1,54) = 3.67, p < .10$). If the strategy advantage of preferred order was effective only after size had been decided, it is possible to infer that size judgements were completed between 100- and 200-msec. after the offset of the first slide. Hence size judgements must have taken approximately 300- to 400-msec. (exposure duration + interstimulus interval) and color judgements took between 400- and 500-msec. since Experiment II showed that color judgements took 100-msec. longer than size judgements. The

drop in RT's to nonpreferred order at the 300-msec. ISI was only slight since color had no contextual advantage in decoding.

These decoding times for size and color contradicted Martin's (1969a) results. If Experiment II can be taken to be a relatively pure measure of decoding time, it is possible that Martin's results truly indicated differences in adjective accessibility. However, decoding in Experiment II was carried out under conditions different from Martin's experiment and these differences themselves may have produced the discrepancy between the results of the two experiments. Martin's experiment involved continuous presentation of attribute information while Experiment II used brief discrete information events. Martin's experiment measured latencies to a verbal response while Experiment II measured manual response latencies. Martin's experiment found the same relation between ordinal position and processing time with many attribute pairs while Experiment II used only size and color. Without further experimentation, the reasons for the discrepancy are unclear.

One further result must be explained, and that is the button order by attribute order interaction. It was found that preferred order was responded to faster if the rows corresponded to sizes than to colors but that nonpreferred order was easier to process when the rows corresponded to colors. This can be accounted for in terms of response organization: the first attribute in each series was used to decide between rows of the button array so that button choice after the second slide had been decoded could be restricted to two possible buttons. If the button array was organized by rows rather than by columns, the results become

understandable. This organization was likely since Ss were told button-to-figure correspondence by rows and all Ss were native speakers (and writers) of English and habitually processed written language in rows rather than columns. The result was not surprising in view of the effects of response organization on adjective order found by Danks (1971) and Danks and Schwenk (1972). The Danks and Schwenk (1972) study demonstrated that inverted adjective order was preferred more frequently when the attribute denoted by the adjective usually appearing closest to the noun (but appearing first in the noun phrase with inverted order) allowed discrimination between possible target objects. Danks (1971) reported reaction time data showing that this preference represented ease of processing: RT's to selecting a target object from a four-object array were shorter to a noun phrase cue with inverted adjective order when the property which allowed discrimination between target objects was ordinarily preferred closest to the noun.

These response organization findings are also consistent with the analysis by synthesis model which suggested that information obtained from early decisions is used to reduce the complexity involved in later decisions.

The results of the experiments, as interpreted above, confirm several hypotheses of the analysis by synthesis model. As predicted, Ss' performance was facilitated when early information was consistent with later information. The facilitative effect of consistency was shown to occur only with the size attribute. No facilitation was found with color, supporting the hypothesis that adjectives preferred farthest from

the noun generate nonterminal decisions referring to the phrase's meaning while adjectives preferred closest to the noun do not. Finding that the interval between early and late information must exceed a 100-msec. minimum for facilitation to occur supported the contention that preferred order minimizes interference by increasing the interval between the noun and difficult-to-process adjectives by interpolating adjectives which do not require as complex processing. Also, finding interval effects contingent on semantic variables (attribute order) suggested the unlikelihood of the simple interval hypothesis proposed earlier and can be taken as evidence for a more complex system.

The application of these results to explain the adjective order phenomenon requires several assumptions. The foremost is that decoding a noun phrase involves a series of decisions about the input which are made as each component of the phrase is input and that the effect of these decisions is to produce some representation of the semantic content of the phrase. Equally important is the assumption that decoding a sequence of visual stimuli involves essentially the same decision-making and construction processes. Direct application of these results to adjective order requires not only the assumption of similarity in the sequence of decisions and in the resultant product but the further assumption that the same mechanism processes both types of information, independent of the input modality. The similarity of the present results to those of Danks et. al. and Stolz suggests that the processes involved in performing the present experimental task are at least similar to those involved in decoding language. Further applicability depends on the

intuitions of the reader and the amount of faith he is willing to invest in them.

The present explanation of the adjective order phenomenon emphasizes the decoding process as the cognitive determinant of the phenomenon and so, stands in opposition to Martin's (1969a, 1969b, 1970) encoding theory. Data from the present experiment and from Danks and his colleagues makes Martin's theory unlikely since they show that the order of adjectives output in encoding is not fixed as Martin's differential accessibility hypothesis would suggest, but depends on semantic considerations, and that adjective order has significant and consistent effects on decoding.

The decoding explanation, including Danks' communication rule operating in conjunction with the analysis by synthesis model, has stronger empirical support than Martin's theory. The major hypothesis of his theory, the differential accessibility of ordinally different adjectives, rests on data from experiments criticized earlier as indicating the differential decoding times of attributes in the stimulus array rather than differential accessibility of adjective meanings. Further consideration shows that the task in those experiments did not, as they were intended, model the encoding task since adjectival meaning was obtained from a visual array rather than from memory as the encoding task would require. Requiring the verbal label of the cued attribute's value as a response was irrelevant since the appropriate words must have been selected only after the appropriate meaning had been obtained and obtaining the appropriate meaning was to have produced the differences. Martin's hypothesis could be more accurately tested in

an experiment measuring latencies to encode ordinally different adjectives from memory. This could be done by requiring subjects to remember arrays of four figures varying in size and color and to recall the position in an array of the figure different from the rest when cued with the array. If the arrays were constructed so that size allowed discrimination of the odd figure in some arrays and color allowed discrimination in others, depth of embeddedness, which was to have determined differential accessibility in Martin's theory, could be assessed by comparing reaction times to recall odd figures with size and color as discriminative attributes. For the subjects to respond correctly, they would have to determine the value of the discriminative attribute of the appropriate figure, so their reaction times would represent the accessibility of that attribute's information from memory.

In any event, Martin's theory of adjective order is not well supported empirically in comparison with the decoding theory. Nor is it as general. The decoding theory can potentially explain several language habits not directly reducable to grammar and would suggest the decoding process as an important focus of research for those interested in determining the psychological processes underlying language. It is possible that a good many of the reasons for the structure of language may lie in the ease with which certain types of structures are inherently processed in the brain.

REFERENCES

- Annear, S.S. The ordering of pre-nomial modifiers in English. Project on Linguistic Analysis Report No. 8, Ohio State University Research Foundation, 1964. Cited in Martin (1969b).
- Brown, R. Social Psychology. New York: Free Press, 1965.
- Collins, A.M. and Quillian, M.R. Retrieval time from semantic memory. Journal of Verbal Learning and Verbal Behavior, 1969, 8, 240-247.
- Danks, J.H. Communication context and prenomial adjective order in English. Paper presented at the Psychonomic Society, St. Louis, 1971.
- Danks, J.H. and Glucksberg, S. Psychological scaling of adjective orders. Journal of Verbal Learning and Verbal Behavior, 1971, 10, 63-67.
- Danks, J.H. and Schwenk, M.A. Prenomial adjective order and communication context. Journal of Verbal Learning and Verbal Behavior, in press 1972.
- Halle, M. and Stevens, K.N. Speech recognition: a model and a program for research. in Fodor, J. and Katz, J. (eds.), The Structure of Language: Readings in the Philosophy of Language, New Jersey: Prentice Hall Inc., 1964.
- Kamin, L.J. The delay-of-punishment gradient. Journal of Comparative and Physiological Psychology, 1959, 52, 434-437.
- Katz, J.J. Semantic theory and the meaning of "good". Journal of Philosophy, 1964, 23, 739-766.
- Kirk, R.E. Experimental Design: Procedures for the Behavioral Sciences, Wadsworth Publishing Co., 1968.
- Kling, J.W. and Riggs, L.A. Woodworth and Schlosberg's Experimental Psychology, Third edition, New York, Holt, Rinehart and Winston Inc., 1971.
- Liberman, A.M., Cooper, F.S., Shankweiler, D.P. and Studdert-Kennedy, M. Perception of the speech code, Psychological Review, 1967, 74, 431-461.
- Lockhart, R.S. and Martin, J.E. Adjective order and the recall of adjective-noun triplets. Journal of Verbal Learning and Verbal Behavior, 1969, 8, 272-275.

- Martin, J.E. Some competence-process relationships in noun phrases with prenomial and postnomial adjectives. Journal of Verbal Learning and Verbal Behavior, 1969a, 8, 471-480.
- Martin, J.E. Semantic determinants of preferred adjective order. Journal of Verbal Learning and Verbal Behavior, 1969b, 8 697-704.
- Martin, J.E. Adjective order and juncture. Journal of Verbal Learning and Verbal Behavior, 1970, 9, 379-383.
- Neisser, U. Cognitive Psychology, New York, Appleton Century Crofts, 1967.
- Stevens, K.N. and Halle, M. Remarks on analysis by synthesis and distinctive features. In Wathen-Dunn, W. (ed.) Models for the Perception of Speech and Visual Form: Proceedings of a Symposium, M.I.T. Press, 1964.
- Stolz, W.S. A study of the Ability to decode grammatically novel sentences. Journal of Verbal Learning and Verbal Behavior, 1967, 6, 867-873.
- Sweet, H. A New English Grammar, Oxford: Clarendon Press, 1898.
- Vendler, Z. The grammar of goodness. Philosophical Review, 1963, 72, 446-465.
- Ziff, P. Semantic Analysis, Ithaca, N.Y.: Cornell University Press, 1960.

FOOTNOTE

¹ In this thesis, encoding will refer to all the processes involved in transforming information in the semantic code to a transmission code. Thus a person uttering a sentence is encoding information. Thus Martin's theory of noun phrase generation is an encoding theory. Decoding will refer to all the processes involved in transforming input information to the semantic code. Thus a person listening to (or reading) and understanding a sentence is decoding information. Thus Danks' theory is a decoding theory. This distinction is admittedly simplistic since simply processing input involves both determining what information is contained in the input code and coding it at a level of organization different from the input. However, such fine distinctions are not necessary to the theories presented here and it is hoped that the heuristic value of consistently using the terms as they are defined here throughout the thesis outweighs whatever detrimental effects this imprecision in terminology may have.

² All orders used in all experiments were generated from an APL function obtained from Dr. S. J. Rule, Department of Psychology, University of Alberta. The function is entitled "ORDERSOF" and samples randomly without replacement from an input table defined by the user. By appropriately defining the input table, the user can control the relative frequency of events in the output sequence. Prior to implementation in the experiments, output sequences were altered to eliminate all runs of more than two successive identical events.

APPENDIX A

SUMMARY OF PILOT RESEARCH

Three formal studies were conducted prior to Experiment I, establishing the exposure durations for information and null events and button-to-figure correspondence. The experiments were identical to Experiment I except in these parameters.

Pilot Experiment A

This experiment used a linear button array and did not vary button order. The button-to-figure correspondence used was, from left to right: large red (LR), small red (SR), large green (LG) and small green (SG). Information events were exposed for 1000-msec. and the variable null event took the following values: 100-, 200-, 300- and 400-msec. Eight native English speaking Ss from an introductory psychology course participated for course credit. The summary of the analysis of variance appears in Table 4-A. On the basis of these results, it was decided to decrease the exposure durations of information events.

Pilot Experiment B

This experiment was identical to Pilot Experiment A except that information event exposure durations were decreased to 500-msec. and 20 Ss from the same subject pool were used. The summary of the analysis of variance appears in Table 4-B. On the basis of these results it was decided to again decrease information event exposure durations.

Pilot Experiment C

This experiment also used a linear button array but varied button-to-figure correspondence as follows: LR, SR, LG, SG and LR, LG, SR, SG. Information events were shortened to 200-msec. and the variable null event took the values used in Experiment I (i.e. 50-, 100-, 200- and 300-msec.). This experiment used 18 Ss from the same subject pool. The summary of the analysis of variance appears in Table 4-C. Since button order interacted significantly with attribute order, it was decided to employ a square button array and again vary button-to-figure correspondence in Experiment I.

TABLE 4-A
SUMMARY OF ANALYSIS OF VARIANCE
FROM PILOT EXPERIMENT A

Source	SSQ	DF	MSQ	F
Subjects	8.244	7	1.178	46.362**
Attribute Order (A)	0.026	1	0.026	1.070
Redundancy (R)	0.279	1	0.279	10.995**
Interval (I)	0.030	3	0.010	
A x R	0.090	1	0.090	3.565
A x I	0.050	3	0.017	
R x I	0.027	3	0.009	
A x R x I	0.100	3	0.033	1.317
Residual	2.667	105	0.025	
Total	11.516	127		

** Significant at the .01 level of probability.

TABLE 4-B
SUMMARY OF ANALYSIS OF VARIANCE
FROM PILOT EXPERIMENT B

Source	SSQ	DF	MSQ	F
Subjects	19.163	19	1.008	103.139**
Attribute Order (A)	0.001	1	0.001	
Redundancy (R)	0.292	1	0.292	29.850**
Interval (I)	0.027	3	0.009	
A x R	0.004	1	0.004	
A x I	0.014	3	0.008	
R x I	0.025	3	0.004	
A x R x I	0.000	3	0.000	
Residual	2.817	288	0.009	
Total	22.346	319		

** Significant at the .01 level of probability.

TABLE 4-C
SUMMARY OF ANALYSIS OF VARIANCE
FROM PILOT EXPERIMENT C

Source	SSQ	DF	MSQ	F
Button Order (B)	0.148	1	0.148	
Error	5.457	16	0.341	
Attribute Order (A)	0.001	1	0.001	
A x B	0.059	1	0.059	3.575
Error	0.266	16	0.017	
Redundancy (R)	0.318	1	0.318	11.450**
R x B	0.022	1	0.022	
Error	0.444	16	0.028	
A x R	0.088	1	0.088	8.533**
A x R x B	0.003	1	0.003	
Error	0.165	16	0.010	
Interval (I)	0.161	3	0.054	4.109*
I x B	0.232	3	0.007	
Error	0.625	48	0.013	
A x I	0.024	3	0.007	
A x I x B	0.132	3	0.044	5.147*
Error	0.410	48	0.008	
R x I	0.170	3	0.056	4.105*
R x I x B	0.015	3	0.005	
Error	0.663	48	0.013	
A x R x I	0.124	3	0.041	2.647
A x R x I x B	0.012	3	0.003	
Error	0.748	48	0.015	
Total	10.084	287		

* Significant at the .05 level of probability.

** Significant at the .01 level of probability.

APPENDIX B

DATA ANALYSIS FROM EXPERIMENT I

The mean RT's across Ss for all insignificant interactions appear in Table 5-A. The summary of the main analysis of variance appears in Table 5-B and the analysis of simple main effects is displayed in Table 5-C.

TABLE 5-A

MEAN RT'S FOR NONSIGNIFICANT INTERACTIONS
IN EXPERIMENT I (IN MSEC.)

	A ₁				R ₁				R ₂				A ₂				R ₂			
	I ₁		I ₄		I ₃		I ₂		I ₃		I ₂		I ₄		I ₁		I ₂		I ₃	
	I ₁	I ₂	I ₃	I ₄	I ₁	I ₂	I ₃	I ₄	I ₁	I ₂	I ₃	I ₄	I ₁	I ₂	I ₃	I ₄	I ₁	I ₂	I ₃	I ₄
B ₁	1037	1005	927	923	862	932	823	840	864	910	907	863	984	889	872	895				
B ₂	1210	1224	1119	1105	1017	1031	1033	999	1150	1158	1172	1128	1266	1042	1253	1277				
	1124	1115	1024	1014	940	982	928	920	1007	1034	1040	996	1125	966	1063	1086				

	I ₁	I ₂	I ₃	I ₄
R ₁	1066	1075	1032	1005
R ₂	1033	974	996	1003
	1049	1024	1014	1004

A₁ - preferred order
 A₂ - nonpreferred order
 R₁ - nonredundant
 R₂ - redundant
 B₁ - rows colors
 B₂ - rows sizes
 I₁ - 50-msec. interval
 I₂ - 100-msec. interval
 I₃ - 200-msec. interval
 I₄ - 300-msec. interval

TABLE 5-B

SUMMARY OF ANALYSIS OF VARIANCE OF RECIPROCAL
RT'S IN EXPERIMENT I

Source	SSQ	DF	MSQ	F
Button Order (B)	3.305	1	3.305	3.713
Error	16.021	18	0.890	
Attribute Order (A)	0.008	1	0.008	
A x B	0.446	1	0.446	4.535*
Error	1.771	18	0.098	
Redundancy (R)	0.417	1	0.417	9.050**
R x B	0.005	1	0.005	
Error	0.830	18	0.046	
A x R	0.354	1	0.354	8.615**
A x R x B	0.011	1	0.011	
Error	0.739	18	0.041	
Interval (I)	0.194	3	0.065	2.382
I x B	0.086	3	0.029	1.056
Error	1.466	54	0.027	
A x I	0.251	3	0.084	5.404**
A x I x B	0.019	3	0.006	
Error	0.834	54	0.015	
R x I	0.044	3	0.015	
R x I x B	0.065	3	0.022	1.093
Error	1.072	54	0.020	
A x R x I	0.075	3	0.025	
A x R x I x B	0.035	3	0.012	
Error	1.466	54	0.027	
Total	29.516	319		

* Significant at the .05 level of probability.

** Significant at the .01 level of probability.

TABLE 5-C
SUMMARY OF SIMPLE MAIN EFFECT ANALYSIS OF
A x R AND A x I INTERACTIONS

Source	SSQ	DF	MSQ	F
A	0.008	1	0.008	
Error	1.771	18	0.098	
A at R ₁	0.508	1	0.508	7.257*
A at R ₂	0.991	1	0.991	14.143**
Error		18	0.070	
R at A ₁	3.090	1	3.090	70.227**
R at A ₂	0.008	1	0.008	
Error		18	0.044	
A x R	0.354	1	0.354	8.615**
Error	0.739	18	0.041	
A at I ₁	0.003	1	0.003	
A at I ₂	0.130	1	0.130	2.722
A at I ₃	0.161	1	0.161	4.472*
A at I ₄	0.132	1	0.132	3.667
Error		54	0.018	
I at A ₁	0.735	3	0.268	12.762**
I at A ₂	0.088	3	0.029	1.381
Error		54	0.021	
A x I	0.251	3	0.084	5.404**
Error	0.834	54	0.015	

* Significant at the .05 level of probability.

** Significant at the .01 level of probability.

A ₁ - preferred order	I ₁ - 50-msec. interval
A ₂ - nonpreferred order	I ₂ -100-msec. interval
R ₁ - nonredundant series	I ₃ -200-msec. interval
R ₂ - redundant series	I ₄ -300-msec. interval

APPENDIX C

DATA ANALYSIS FROM EXPERIMENT II

The summary of the pre-test analysis of variance appears in Table 6-A and the summary of the main analysis of variance appears in Table 6-B. The summary of Duncan's new multiple range analysis of differences between cell means from the main analysis of variance is displayed in Table 6-C.

TABLE 6-A
SUMMARY OF PRETEST ANALYSIS OF VARIANCE
IN EXPERIMENT II

Source	SSQ	DF	MSQ	F
Button Order (B)	0.0009	1	0.0009	
Error	1.928	18	0.107	
Dimensions - total figures (D)	0.009	1	0.009	
D x B	0.008	1	0.008	
Error	0.640	18	0.036	
Total	2.587	39		

TABLE 6-B
SUMMARY OF ANALYSIS OF VARIANCE OF RECIPROCAL
RT'S IN EXPERIMENT II

Source	SSQ	DF	MSQ	F
Subjects	2.243	19	0.118	3.705**
Number of Attributes (N)	1.184	1	1.184	37.139**
Dimensions (D)	0.124	1	0.124	3.874
D x N	0.048	1	0.048	1.514
Error	1.813	57	0.032	
Total	5.415	79		

* Significant at the .05 level of probability.

** Significant at the .01 level of probability.

TABLE 6-C

SUMMARY OF DUNCAN'S NEW MULTIPLE RANGE ANALYSIS OF DIFFERENCES
BETWEEN MEAN RECIPROCAL RT'S IN EXPERIMENT II

Condition:	N_2D_2	N_2D_1	N_1D_2	N_1D_1
Mean Reciprocal RT:	.986	1.016	1.181	1.308
Rank Order:	1	2	3	4
1		.030	.195**	.322**
2			.165**	.292**
3				.127*

* Significant at the .05 level of probability.

** Significant at the .01 level of probability.

Values of q for $df = 60$

for $p < .05$

$$q_2 = .113$$

$$q_3 = .119$$

$$q_4 = .123$$

for $p < .01$

$$q_2 = .150$$

$$q_3 = .156$$

$$q_4 = .161$$

N_1 - single attribute

N_2 - bi-attribute

D_1 - last attribute was size

D_2 - last attribute was color

APPENDIX D

DATA ANALYSIS FROM EXPERIMENT III

The summary of the analysis of variance performed on reciprocal RT's is displayed in Table 7.

TABLE 7
SUMMARY OF ANALYSIS OF VARIANCE OF RECIPROCAL
RT'S IN EXPERIMENT III

Source	SSQ	DF	MSQ	F
Button Order (B)	0.021	1	0.021	
Error	3.661	18	0.203	
Trial Types (T)	0.711	4	0.178	8.776**
T x B	0.136	4	0.034	1.678
Error	1.459	72	0.020	
Total	5.988	99		

** Significant at the .01 level of probability.

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